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# INVESTIGATION OF SLUMPING FAILURE IN AN EARTH DAM ABUTMENT AT KOTZEBUE, ALASKA

Charles M. Collins and Terry T. McFadden



July 1977

Prepared for
U.S. PUBLIC HEALTH SERVICE
By
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A slumping failure on the upstream side in one area of the water supply reservoir at Kotzebue, Alaska, was investigated. Seven 80-ft (24.4-m) thermocouple strings were emplaced in the dam abutment, and an additional four thermocouple strings were installed behind the dam, extending to a depth of 95 ft (28.9 m) below the bottom of the reservoir. All thermocouples indicated below freezing temperatures at their respective positions. These measurements combined with the drill logs indicate that neither the dam nor

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the abutment is in immediate danger of failure, but that steps must be taken to stop the sloughing of material in the abutment area. Recommendations are given to accomplish this.

## PREFACE

This report was prepared by Charles M. Collins, Physical Scientist, and Dr. Terry T. McFadden, Supervisory Mechanical Engineer, of the Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL).

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Technical review of this report was performed by Francis H. Sayles of CRREL.

Special thanks are given to Irv Long and Francis H. Sayles, who visited the damsite and offered suggestions and opinions on the research and recommendations.

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INVESTIGATION OF SLUMPING FAILURE IN AN
EARTH DAM ABUTMENT AT KOTZEBUE, ALASKA

Charles M. Collins and Terry T. McFadden

## Introduction

In April 1976 the Alaska Area Native Health Service of the U.S. Public Health Service contacted the U.S. Army Cold Regions Research and Engineering Laboratory to request a study of the subsidence that was occurring on one of the abutments of the Kotzebue-Vortac Dam. The dam is an earth embankment that allows the level of the natural lake to be raised, thus providing more water storage capacity. This is the water supply reservoir for the town of Kotzebue. A detailed description of the site is given below.

In May 1976 authorization to proceed with the study was given. An emergency contract was immediately issued to Jim Thrasher and Associates for the drilling of four thermocouple probe holes. The drill rig was

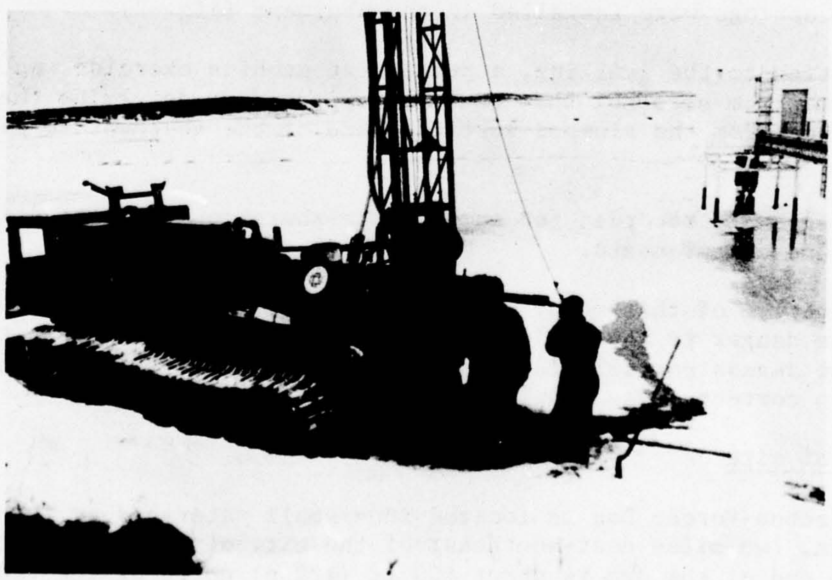

*Figure 1. Drill rig on the ice behind the dam.*

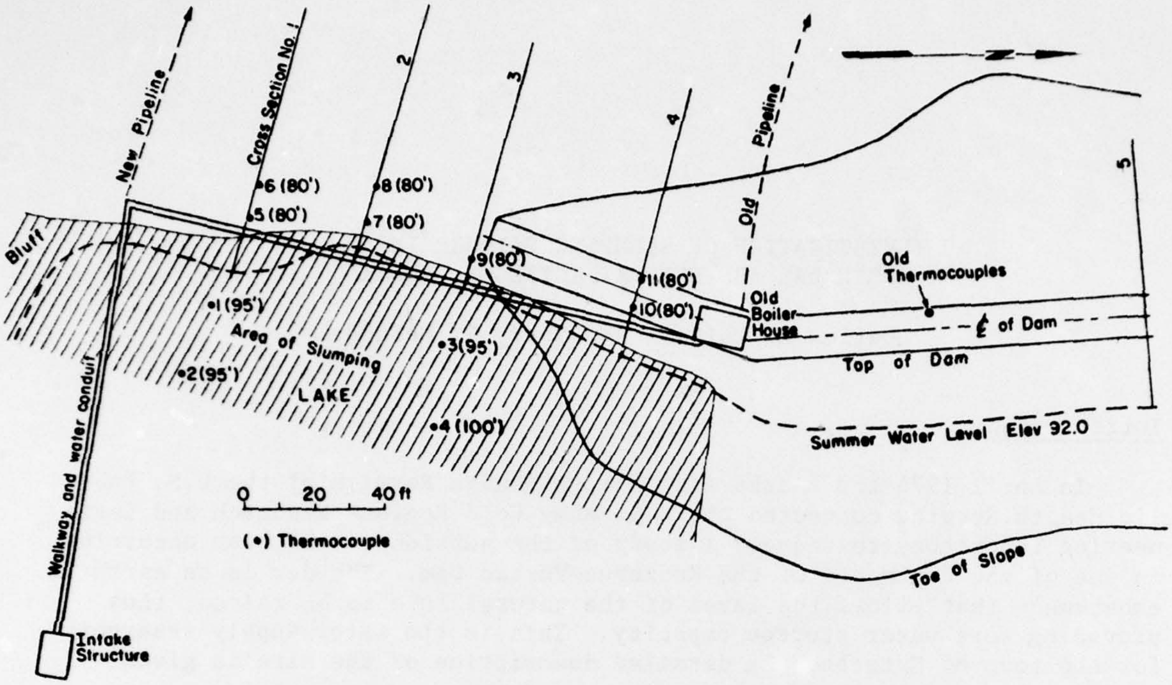


*Figure 2. Location of drill holes with thermocouple assemblies and cross sections, Vortac Dam, Kotzebue, Alaska.*

placed on the ice behind the dam and holes were sunk into the upstream base of the dam (Fig. 1). Later in the summer, seven additional holes and thermocouple strings were installed in the abutment (Fig. 2).

In addition to the drilling, a permafrost probing exercise was conducted when maximum seasonal thaw could be expected to determine the horizontal distance from the slumped vertical face of the abutment to permafrost.

Drill logs were recorded for each of the thermocouple holes drilled for temperature measurements.

The objective of this study was to determine the extent of thawing, to assess the danger to the dam's stability that may exist at this time, and to try to assess possible future problems that could arise. Recommendations to correct these problems are made.

## Description of site

The Kotzebue-Vortac Dam is located in a small watershed on the Baldwin Peninsula, two miles east-southeast of the city of Kotzebue (Fig. 3). The southern end of the dam is about 400 ft (122 m) north of the Federal Aviation Administration (FAA) Vortac station, hence its name. The damsite is accessible in summer by tracked vehicle along a roundabout trail skirting a lagoon just east of town, or by boat directly across the lagoon and

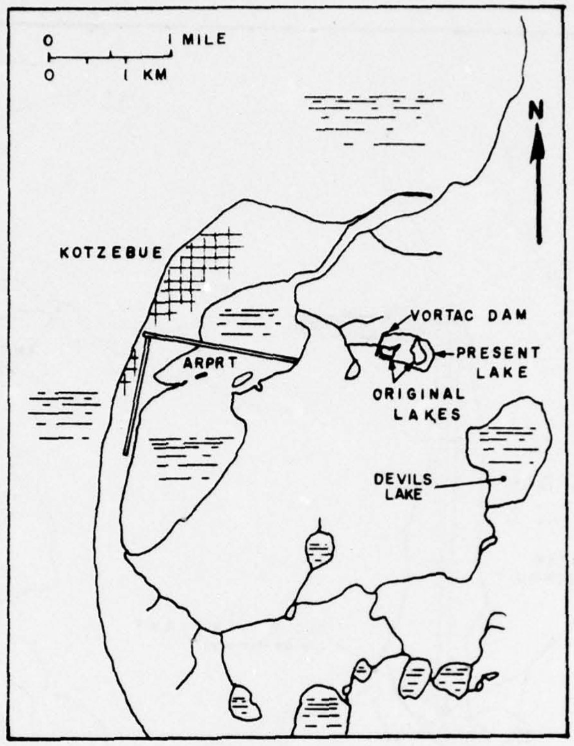


*Figure 3. Map of Kotzebue area and damsite location*

then by walking. In the winter, access is readily available across the ice of the lagoon. An all-weather access road to the Vortac facility is scheduled for construction in 1977 by FAA.

The damsite was located to take advantage of two small lake basins already present within the watershed. The present reservoir level is about 15 ft (4.6 m) above the preexisting Vortac Lake and 10 ft (3.1 m) above the second lake (Fig. 3). This effectively quadruples the water surface area and stores approximately 150 million gallons of water for city consumption. During the summer supplemental water can be pumped into the reservoir from Devils Lake, in a different watershed about a half mile to the southeast (Fig. 3).

The terrain surrounding the damsite consists of low, rolling, tundra-covered hills with elevations up to 140 ft (42.7 m). There is some small brush in protected draws.

The Kotzebue region is generally underlain by continuous permafrost. *The Permafrost Map of Alaska* (Ferrians 1965) indicates that permafrost in this region has an average thickness of 238 ft (72.6 m). The annual active thaw layer under the tundra is shallow [12 to 18 in. (0.3 to 0.5 m) in vegetated areas]. The top of the permafrost table was approximately 50 ft (15.3 m) below the surface of the original Vortac Lake as determined by drilling for the pilings of the water intake structure (U.S. PHS 1975).

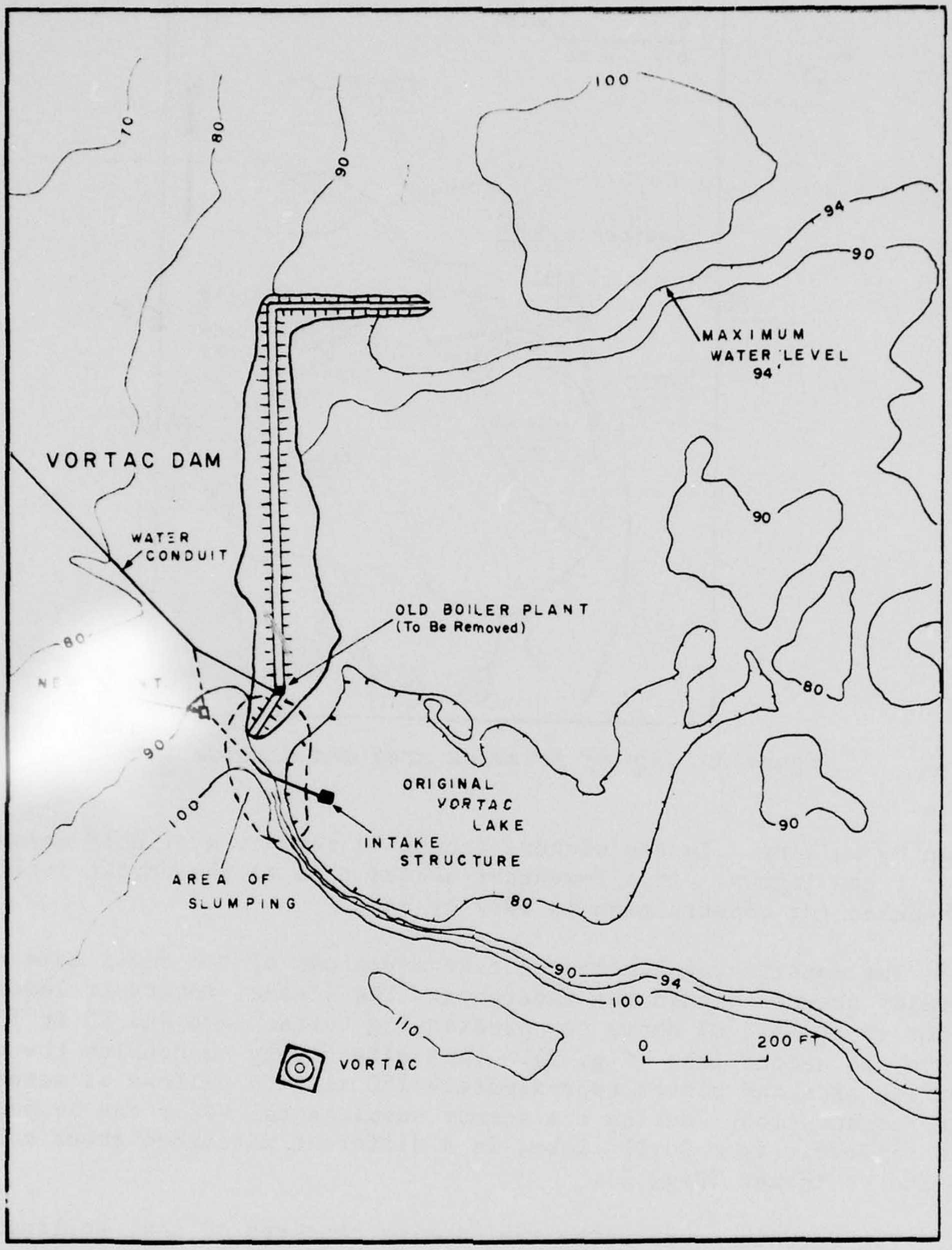


*Figure 4. Enlarged map of damsite.*

The dam embankment was constructed from silt taken from the damsite area. Material was placed by mixing frozen ripped material with thawed moist silt. The material was then compacted and allowed to refreeze (U.S. PHS 1975).

The dam averages about 20 ft (6.1 m) in height, 180 ft (54.9 m) in width along the base and 10 ft (3.1 m) in width at the crest. It is abutted to low bluffs on the south, then runs for a 70-ft (21.3-m) stretch

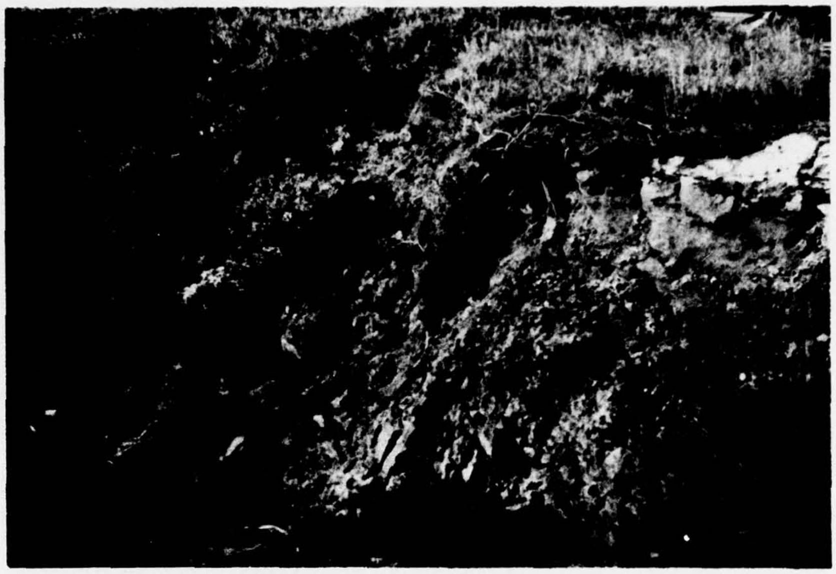

*Figure 5. Slumping of natural embankment along the southwest shore of the lake.*

north-northeast. This portion of the dam is adjacent to the slope failure. At the old boiler plant the dam makes a dogleg and runs almost due north for 650 ft (198.3 m) before it makes a second turn to the east and runs for another 250 ft (76.3 m) (Fig. 4). The maximum height of reservoir water surface is within 2 ft (0.6 m) of the crest of the dam when the lake is full in the fall.

A water intake structure is located in the lake, near the south end of the dam, about 100 ft (30 m) from shore. A walkway and water conduit extends from this structure to the dam abutment at the southern end. The conduit originally ran along the crest of the dam to a boiler plant [a 12- by 16-ft (3.7- by 4.9-m) wood frame structure located at the first turn in the dam, 70 ft (21.3 m) from the south end]. From the boiler plant, the conduit ran west down the face of the dam toward the town. In the fall of 1976 a new, larger-capacity boiler plant was constructed off the dam, toward the southwest, eliminating two $90^{\circ}$ turns of the conduit and removing the conduit and the boiler plant from the crest of the dam (Fig. 4).

## Investigation and Measurements

A visual inspection of the dam showed that the slumping problem is confined along the southern 70-ft (21.3-m) of the dam and abutment. This southernmost leg is where the embankment abuts the low bluffs that form the south shore of the original lake. In this area the original bluffs had been augmented with silt fill where needed.

Slumping and collapse are occurring along the steep bank facing the water from approximately the boiler plant to the southern end of the dam where it joins the bluffs (Fig. 2). Slumping from these bluffs is also visible along the southwest side of the lake (Fig. 5).

*Figure 6. Thermocouple hole being drilled in the crest of the dam. Note the extensive amount of clear ice being extracted from the hole.*

In April 1976, Jim Thrasher and Associates, under contract with CRREL, drilled four holes through the ice on the upstream face of the dam and abutment face near the south end (Fig. 2, holes 1-4). The drill logs of these holes are shown in Figures A1-A4 (App. A). Thermocouple assemblies were installed in each hole with thermocouples at 47, 63, 79, 87 and 95 ft below the reservoir bottom. The purpose of the drilling was to determine the location of any thaw buib that might exist under the lake and to determine if the thaw bulb extended below or into the dam. The enlargement of this thaw bulb due to reservoir filling could account for the slumping at the southern abutment.

None of the thermocouples in the holes indicated a thawed condition; that is, the thaw bulb below the lake did not extend as deep as the topmost thermocouple on any of the strings.

In August 1976, Jim Thrasher and Associates drilled seven 80-ft holes (Fig. 6) on the dam crest adjacent to and through the southern abutment (Fig. 2, holes 5-11). Thermocouple assemblies were installed with thermocouples at 10-ft (3-m) intervals to a depth of 80 ft (24 m).

The drill logs (Fig. A5-A11, App. A) and the thermocouple readings (Table I) show that the dam construction has not disturbed the natural permafrost. Except in the reservoir, all of the material below 2 to 3 ft (0.6 to 1 m) from the surface was frozen. In many of the holes a large amount of massive ice was present [over 20 ft (6-m)]; some of it was very near the surface. This ice was present before the dam was built. However, melting is taking place along the steep, unprotected vertical face of the south dam abutment on the upstream side. Melting of these massive ice

structures is causing the silty soil to slump and collapse. Wave action then contributes further by eroding away the collapsed material.

Five cross sections were made across the dam (see Fig. 2 for locations). Figures B1-B5 (App. B) show these cross sections. The cross section shown in Figure B2 gives the location of permafrost probings which were made in the near vertical upstream bank of the dam abutment and shows the zone of thawed material.

Each of the first four cross sections is in the area south of the boiler plant where slumping has taken place. The areas that have collapsed are apparent in the cross sections, especially where the material has sloughed out from beneath the elevated water conduit.

The last cross section is in the man-made portion of the dam north of the boiler plant. The difference in slope on both faces of the dam is apparent when comparison is made with the first four cross sections.

Drilling was not possible in this area of the dam because the location of the water conduit blocked access by the drill rig. However, four thermocouples previously installed at 5-ft intervals (Crum 1976) below the dam crest were found (Fig. 2). Readings of these thermocouples all indicated frozen conditions in this portion of the dam, as shown in Table I.

## Results and Conclusions

The observations of this study suggest that, although not immediate, the possibility of failure in the south abutment does exist. It would be caused by the gradual, progressive advancement of the melt line and the subsequent slumping failure of the nearly vertical slopes of the original soils. The problem is confined to the south abutment, where the earthfill dike adjoins the natural terrain, and is due to the high ice content of the natural ground in this area. As is seen in drill logs (Fig. A5-A11, App. A), several tens of feet of clear ice are present in this portion of the structure. The progressive melting is caused by heat flux from the water into the frozen soil. As the ice structures melt, the silty soil sloughs off and collapses (Fig. 7). This exposes a new surface to the melting action of the water and the $0^{\circ}C$ isotherm progresses farther into the abutment. It is conceivable that this process could continue until the dam has been breached in this area.

The depth of the thaw bulb beneath the reservoir was not measured at this time; however, it must be less than 47 ft, since all of the thermocouples installed behind the dam show that the portions of the dam which are being measured are below freezing. The thermocouple readings along with the probing and drill logs show that the dam is frozen and is in no immediate danger of failure. All presently observable problems are confined to the south abutment where the embankment adjoins at the south end. No signs of failure or stress of any kind could be found in the embankment of the dam or the north abutment. A composite cross section of the south abutment shows the probable extent of the thaw bulb underneath the reservoir (Fig. 8).

Table I. Thermocouple readings at Kotzebue-Vortac Dam.
(All temperatures in °Celsius.)

| Hole No. | T.C. No. | 5/9/76* | 6/22/76 | 8/7/76 | 8/19/76 | 8/31/76 | 12/9/76** |
|---|---|---|---|---|---|---|---|
| 1 | 5 | -0.6°C | -1.1 | -1.4 | -1.3 | -1.5 | -1.2 |
| | 4 | -0.9 | -1.5 | -1.7 | -1.8 | -1.8 | -1.6 |
| | 3 | -1.7 | -1.3 | -1.7 | -1.6 | -1.7 | -1.6 |
| | 2 | -1.8 | -1.4 | -1.8 | -1.7 | -1.7 | -1.6 |
| | 1 | -1.3 | -1.2 | -1.7 | -1.5 | -1.7 | -1.5 |
| 2 | 5 | -0.6 | -0.95 | -1.2 | -1.1 | ---- | ---- |
| | 4 | -0.6 | -1.0 | -1.4 | -1.2 | -1.4 | ---- |
| | 3 | -1.4 | -1.1 | -1.5 | -1.5 | -1.4 | ---- |
| | 2 | -1.6 | -1.2 | -1.6 | -1.5 | -1.4 | ---- |
| | 1 | -1.1 | -1.2 | -1.7 | -1.8 | -1.8 | ---- |
| 3 | 5 | -0.6 | -1.2 | -1.3 | ---- | -1.1 | ---- |
| | 4 | -0.8 | -1.3 | -1.5 | ---- | -1.4 | ---- |
| | 3 | -0.8 | -1.4 | -1.7 | ---- | -1.7 | ---- |
| | 2 | -1.7 | -1.3 | -1.7 | ---- | -1.7 | ---- |
| | 1 | -0.6 | -1.5 | -1.8 | ---- | -1.8 | ---- |
| 4 | 5 | -0.6 | -0.9 | -1.6 | ---- | ---- | ---- |
| | 4 | -0.5 | -1.1 | -1.8 | ---- | -1.6 | ---- |
| | 3 | -0.9 | -1.3 | -1.8 | ---- | -1.8 | ---- |
| | 2 | -1.1 | -1.3 | -1.8 | ---- | -1.8 | ---- |
| | 1 | -0.6 | -1.4 | -1.6 | ---- | -2.1 | ---- |
| 5 | 8 | ---- | ---- | ---- | -1.2 | -1.8 | -0.9 |
| | 7 | ---- | ---- | ---- | -1.6 | -2.1 | -1.6 |
| | 6 | ---- | ---- | ---- | -1.8 | -1.8 | -1.6 |
| | 5 | ---- | ---- | ---- | -1.6 | -1.8 | -1.6 |
| | 4 | ---- | ---- | ---- | -1.6 | -1.7 | -1.6 |
| | 3 | ---- | ---- | ---- | -1.6 | -1.7 | -1.6 |
| | 2 | ---- | ---- | ---- | -1.6 | -1.7 | -1.6 |
| | 1 | ---- | ---- | ---- | -1.3 | -1.8 | -1.7 |
| 6 | 8 | ---- | ---- | ---- | -2.2 | -2.4 | ---- |
| | 7 | ---- | ---- | ---- | -2.3 | -2.5 | ---- |
| | 6 | ---- | ---- | ---- | -1.8 | -2.2 | ---- |
| | 5 | ---- | ---- | ---- | -0.6 | -1.9 | ---- |
| | 4 | ---- | ---- | ---- | -0.4 | -1.8 | ---- |
| | 3 | ---- | ---- | ---- | -0.8 | -1.9 | ---- |
| | 2 | ---- | ---- | ---- | -0.7 | -1.8 | ---- |
| | 1 | ---- | ---- | ---- | -1.5 | -1.9 | ---- |
| 7 | 8 | ---- | ---- | ---- | -2.0 | -2.0 | -1.2 |
| | 7 | ---- | ---- | ---- | -2.1 | -2.4 | -1.5 |
| | 6 | ---- | ---- | ---- | -1.8 | -2.1 | -1.5 |
| | 5 | ---- | ---- | ---- | -1.7 | -1.8 | -1.5 |
| | 4 | ---- | ---- | ---- | -1.5 | -1.4 | -1.5 |
| | 3 | ---- | ---- | ---- | -1.6 | -1.8 | -1.6 |
| | 2 | ---- | ---- | ---- | -1.6 | -1.8 | -1.6 |
| | 1 | ---- | ---- | ---- | -1.5 | -1.8 | -1.6 |

Table I (Cont'd).

| Hole No. | T.C. No. | 5/9/76* | 6/22/76 | 8/7/76 | 8/19/76 | 8/31/76 | 12/9/76** |
|---|---|---|---|---|---|---|---|
| 8 | 8 | ---- | ---- | ---- | -1.6 | -2.5 | -1.4 |
| | 7 | ---- | ---- | ---- | -2.5 | -2.7 | -1.9 |
| | 6 | ---- | ---- | ---- | -2.0 | -2.5 | -2.0 |
| | 5 | ---- | ---- | ---- | -1.8 | -2.2 | -1.9 |
| | 4 | ---- | ---- | ---- | -1.6 | -1.9 | -1.7 |
| | 3 | ---- | ---- | ---- | -1.8 | -1.8 | -1.6 |
| | 2 | ---- | ---- | ---- | -1.7 | -1.9 | -1.7 |
| | 1 | ---- | ---- | ---- | -1.6 | -1.8 | -1.6 |
| 9 | 8 | ---- | ---- | ---- | -0.3 | -1.9 | -1.0 |
| | 7 | ---- | ---- | ---- | -0.4 | -2.5 | -1.9 |
| | 6 | ---- | ---- | ---- | -0.4 | -2.4 | -1.9 |
| | 5 | ---- | ---- | ---- | -0.3 | -2.2 | -1.9 |
| | 4 | ---- | ---- | ---- | -0.4 | -2.1 | -1.6 |
| | 3 | ---- | ---- | ---- | -0.8 | -2.2 | -1.6 |
| | 2 | ---- | ---- | ---- | -0.4 | -2.0 | -1.7 |
| | 1 | ---- | ---- | ---- | -1.1 | -1.9 | -1.8 |
| 10 | 8 | ---- | ---- | ---- | -2.7 | -2.6 | -2.2 |
| | 7 | ---- | ---- | ---- | -3.1 | -3.0 | -2.2 |
| | 6 | ---- | ---- | ---- | -2.5 | -2.7 | -2.2 |
| | 5 | ---- | ---- | ---- | -2.1 | -2.4 | -2.2 |
| | 4 | ---- | ---- | ---- | -2.0 | -2.1 | -2.0 |
| | 3 | ---- | ---- | ---- | -1.9 | -2.1 | -1.9 |
| | 2 | ---- | ---- | ---- | -1.8 | -2.0 | -1.9 |
| | 1 | ---- | ---- | ---- | -1.8 | -2.0 | -1.9 |
| 11 | 8 | ---- | ---- | ---- | -2.0 | -2.7 | -1.5 |
| | 7 | ---- | ---- | ---- | -3.1 | -3.6 | -2.3 |
| | 6 | ---- | ---- | ---- | -2.8 | -3.1 | -2.3 |
| | 5 | ---- | ---- | ---- | -2.4 | -2.6 | -2.2 |
| | 4 | ---- | ---- | ---- | -2.2 | -2.3 | -2.1 |
| | 3 | ---- | ---- | ---- | -1.3 | -2.5 | ---- |
| | 2 | ---- | ---- | ---- | -0.7 | -2.0 | -1.9 |
| | 1 | ---- | ---- | ---- | -1.5 | -2.0 | -1.9 |

*Thermocouple string as of this date may not yet be at equilibrium.
**Temperatures on this date were corrected for drift of measuring instrument.

Holes 1 thru 4 (below lake bottom:
- 5 - 47 ft
- 4 - 63 ft
- 3 - 79 ft
- 2 - 87 ft
- 1 - 95 ft

Holes 5 thru 11 (below surface):
- 8 - 10 ft
- 7 - 20 ft
- 6 - 30 ft
- 5 - 40 ft
- 4 - 50 ft
- 3 - 60 ft
- 2 - 70 ft
- 1 - 80 ft

| Old thermocouple readings (31 Aug 76): | Depth below crest |
|---|---|
| 0. - 0.7 | 5 ft |
| 1. - 3.5 | 10 ft |
| 2. - 3.3 | 15 ft |
| 3. - 2.6 | 20 ft |

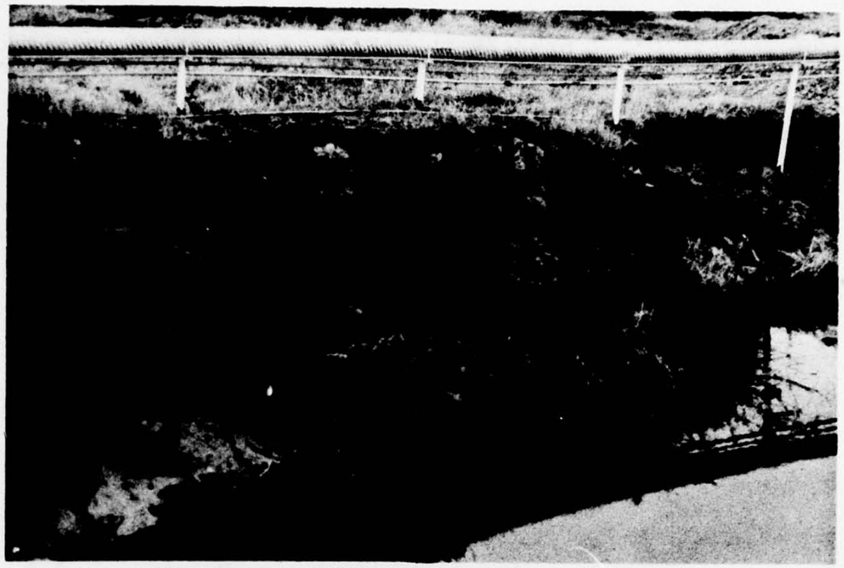

*Figure 7. View of slumping abutment.*

The continual raising and lowering of the water level is detrimental to the performance and lifetime of the embankment. Each time the water level is raised, heat flows into this newly inundated portion causing melting and slumping. When the water level subsides, this area is left to come to equilibrium with the atmospheric conditions which in summer are more conducive to continued melting rather than any refreezing. It would, therefore, be desirable to maintain as stable a water level as is practical (without hindering use of the dam as a water supply). It would also be desirable to maintain a low water level during the winter months so that areas in the embankment could be allowed to refreeze. However, refreezing may be thwarted by the large snow drifts that accumulate on the upstream side of the dam. These drifts effectively insulate the embankment from the winter temperature extremes, and much of the desired freezing (Fig. 9).

The problem is a combination of erosion and melting, since the melting will not continually progress without the accompanying erosion and slumping of the embankment. Slumping is largely a function of the slope of the dam embankment and the thawed strength of the soil. The upstream portion of the south abutment is far too steep (Fig. B1-B4, App. B). This can all be corrected with the addition of nonfrost-susceptible fill on the upstream side of the dam to restore its slope to one which approaches that which is found on the man-made portion of the dam (Fig. B5, App. B). This is an approximate 7:1 slope. A means of eliminating erosion such as riprapping would also help eliminate wave erosion problems that presently exist.

The resloping of this portion of the embankment would cause the $0^{\circ}C$ isotherm to move back into the nonfrost-susceptible fill and would exclude it from the ice-rich portions of the embankment. This should also be instrumental in stopping any further erosion or failure.

The use of refrigeration does not appear necessary or advisable at this time.

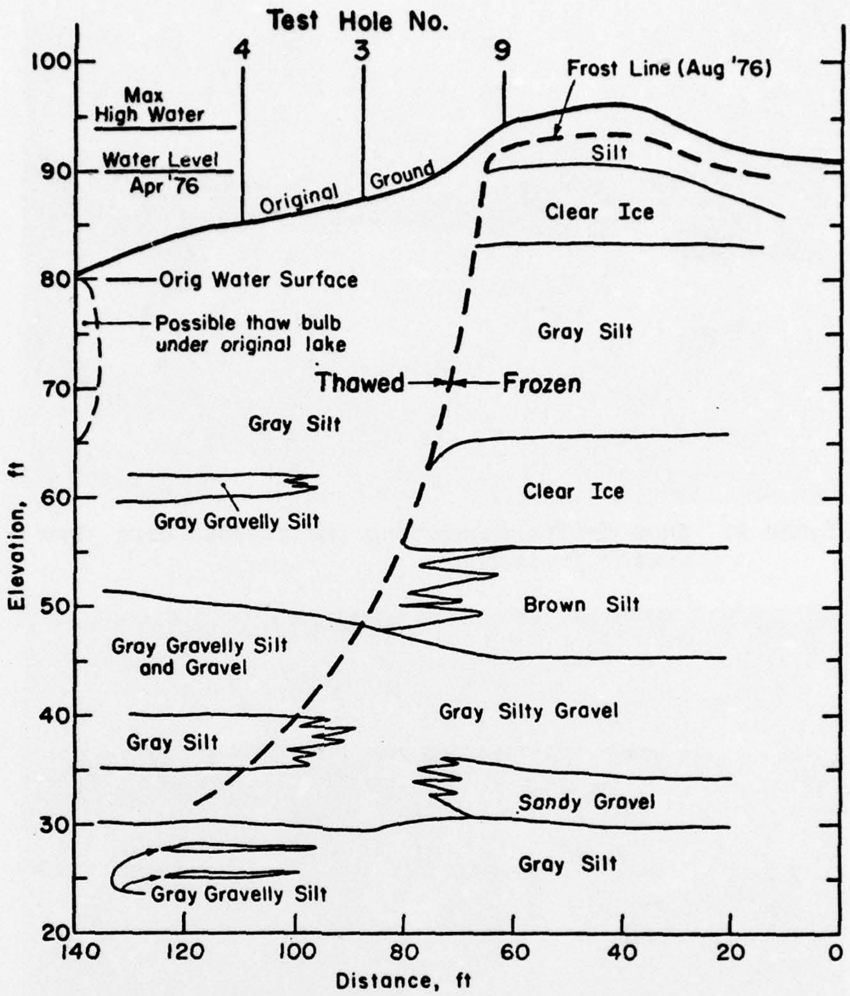


*Figure 8. Thaw bulb in Vortac Dam south abutment.*

Recommendations

The following recommendations are based on the measurements and observations of this study:

1. The upstream side of the embankment at the south abutment of the dam should be refilled to bring the slope to a much shallower configuration, something approximating that of the man-made embankment (Fig 10 and Fig. B5, App. B) a few yards to the north. This will involve hauling in several hundred cubic yards of embankment fill, such as clean gravel, which is not frost-susceptible. This should be done with the water at the lowest possible level so that the resloping can be as effective as possible. Particular care should be taken to protect the pole foundation under the west end of the bridge carrying the water conduit between the south abutment and the intake structure.

The addition of a hard riprapping material on top of the fill would be good practice and would help to avoid any further erosion due to wave

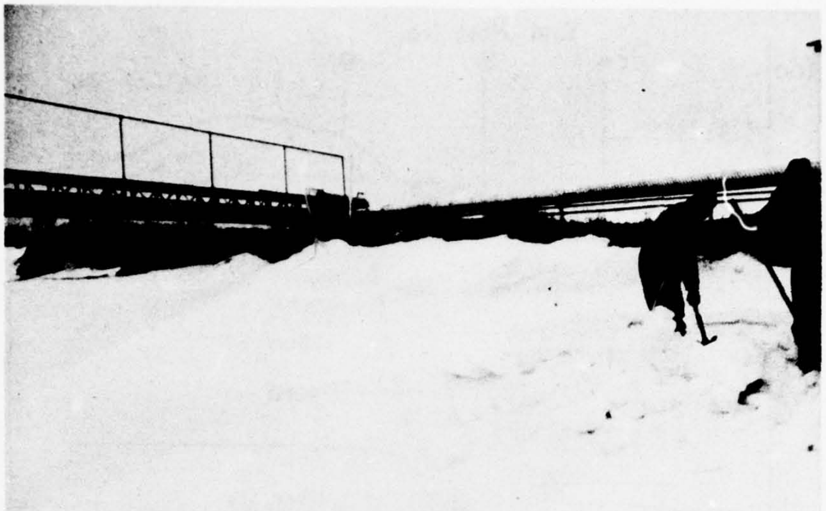

*Figure 9. Snow drifts insulating the slumped area from winter freezeback.*

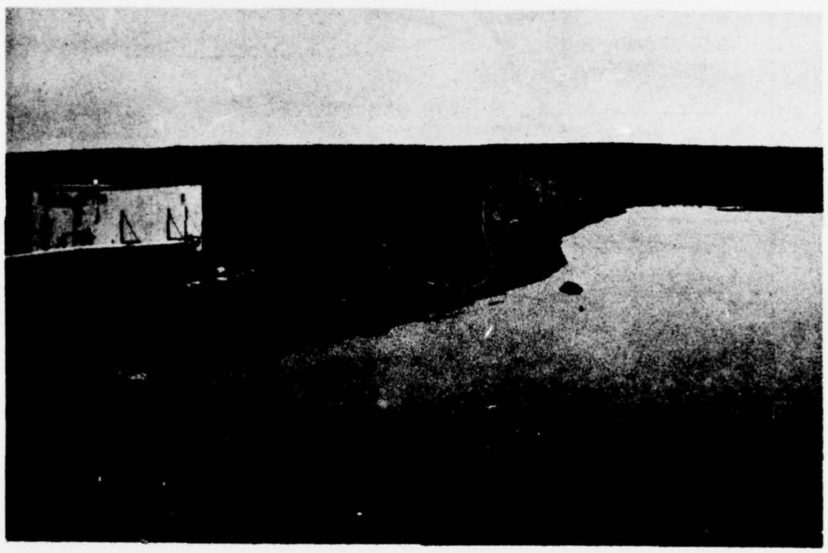

*Figure 10. Man-made embankment.*

action. Perforated metal plank such as that used in runways would be adequate for this purpose. Other materials such as broken concrete pipe or similar material would also be acceptable.

2. The area around the dam should be cleaned up. Piles of gravel are sitting on the dam crest where they serve no useful purpose and cause snow drifting, which insulates the embankment from the winter cold. In addition, a good deal of debris from construction is scattered around the area and serves only to insulate portions of the embankment that should

not be so protected. Removal of the old boiler plant and all related equipment after the new boiler plant is installed is a step in this direction.

3. The embankment should be vegetated. This will allow protection from the summer sun and yield a shallower summer active layer while not substantially reducing the winter freezeback.

4. The water level in the reservoir behind the dam should be maintained at the lowest practical level during the winter months. The level should not be varied any more than is necessary for the dam to adequately fulfill its function as a water supply reservoir.

5. Traffic along the frost-susceptible portions of the dam should be restricted as much as possible to minimize melting of the massive ice formations that are near the surface and extend to considerable depth (Fig. A5, A6, A9, App. A). Access areas should be adequately protected from damage due to traffic by either catwalks or insulated roadway embankments. This is particularly of concern in the vicinity of the south abutment.

6. The thermocouple strings which have been emplaced at considerable expense should be protected during the fill and resloping operation. This will allow the continued monitoring of the thermal regime within and under the dam and give an early alert of any problems that might arise in the future.

Monitoring these thermocouple strings twice a year, once in May and again in September, should give adequate warning of any thermal problem that might develop.

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APPENDIX A: DRILL LOGS FOR THERMOCOUPLE HOLES AT VORTAC DAM

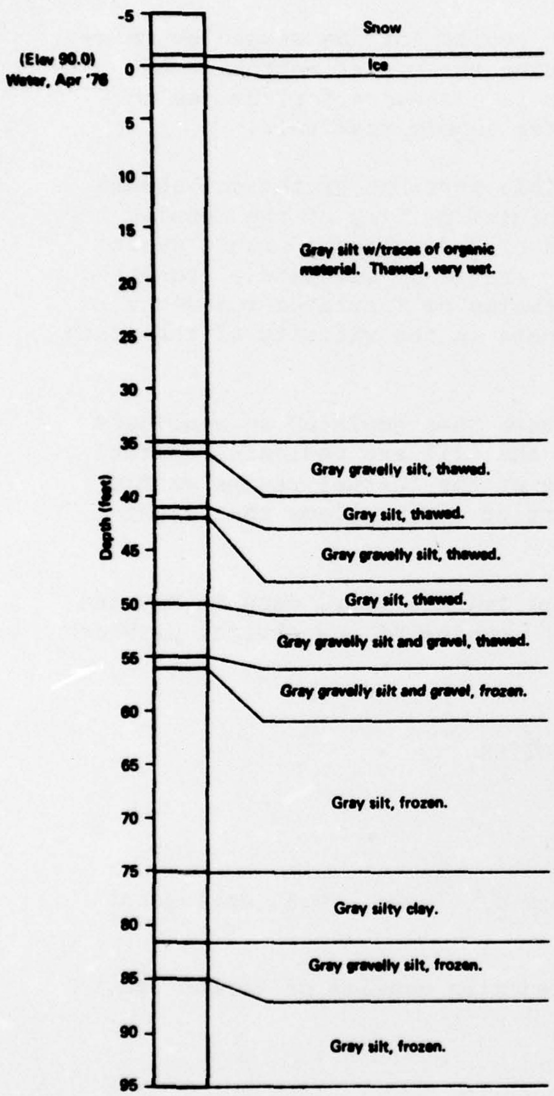


*Figure A1. Drill log for hole no. 1.*

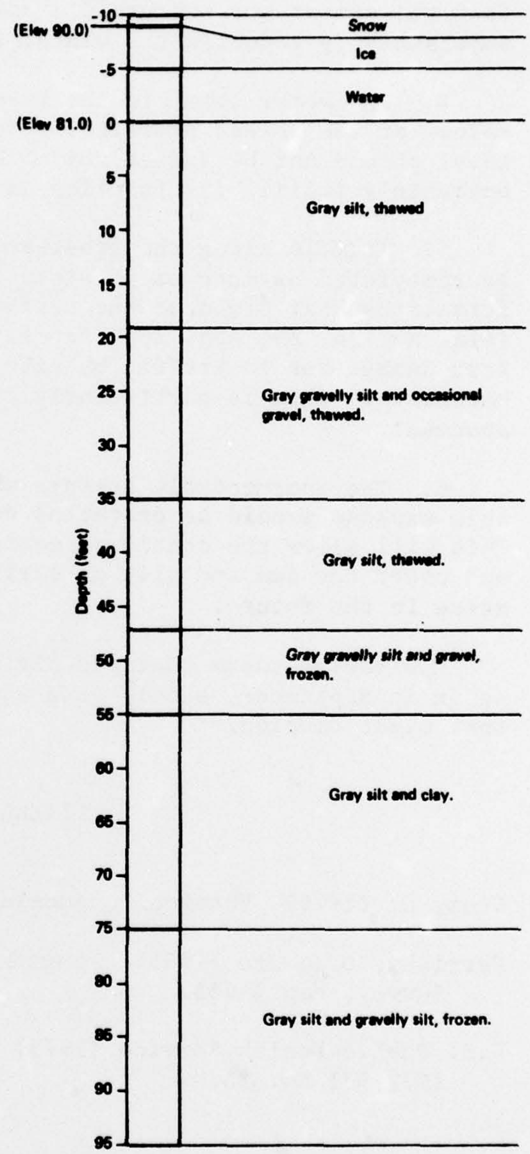


*Figure 2. Drill log for hole no. 2.*

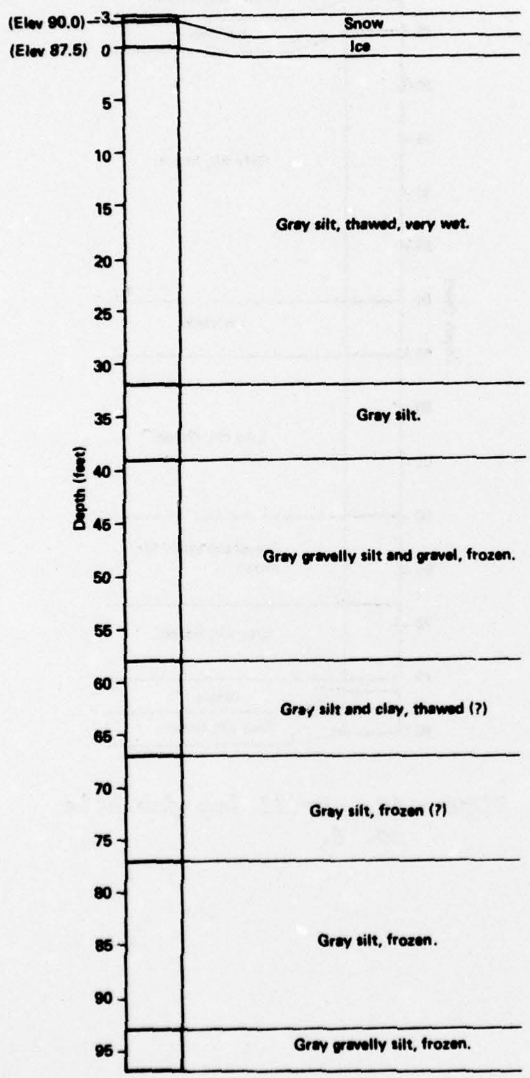


*Figure A3. Drill log for hole no. 3.*

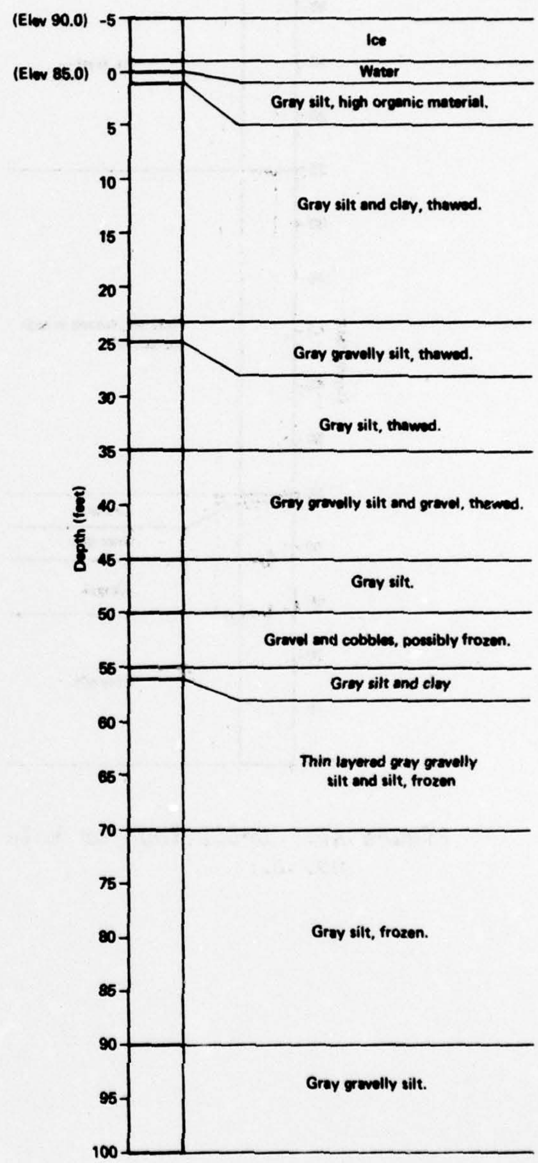


*Figure A4. Drill log for hole no. 4.*

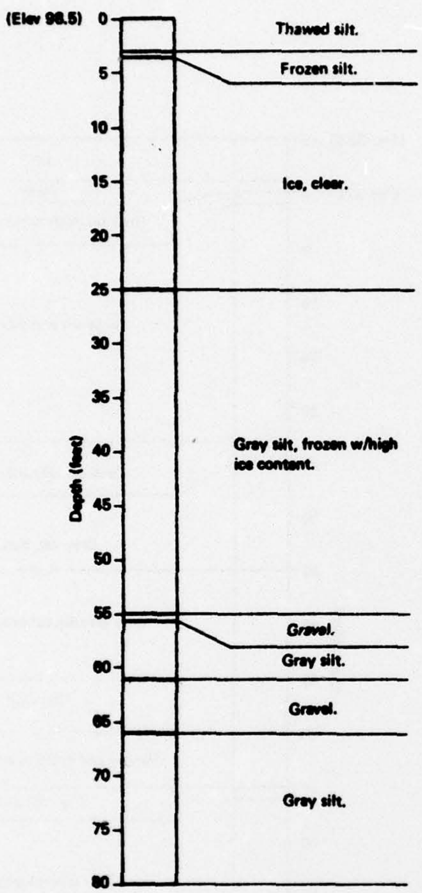


Figure A5. Drill log for hole no. 5.

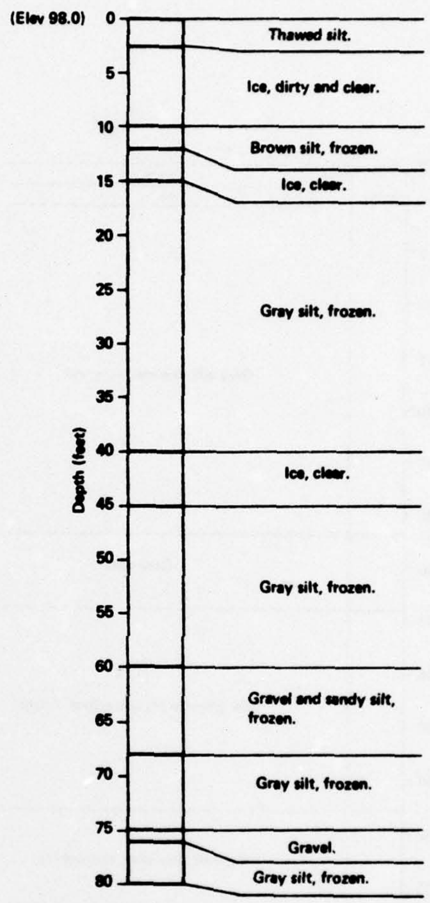


Figure A6. Drill log for hole no. 6.

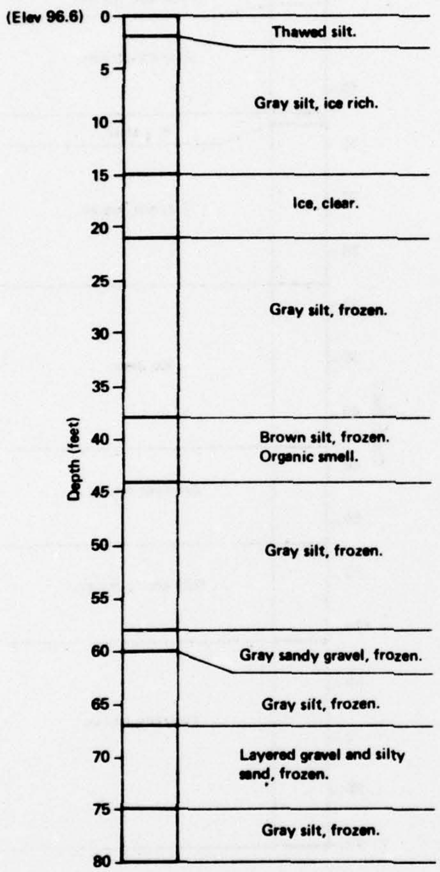


*Figure A7. Drill log for hole no. 7.*

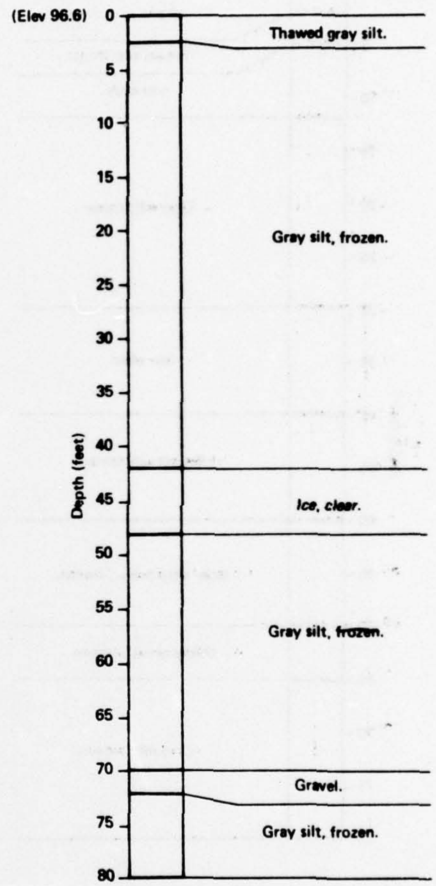


*Figure A8. Drill log for hole no. 8.*

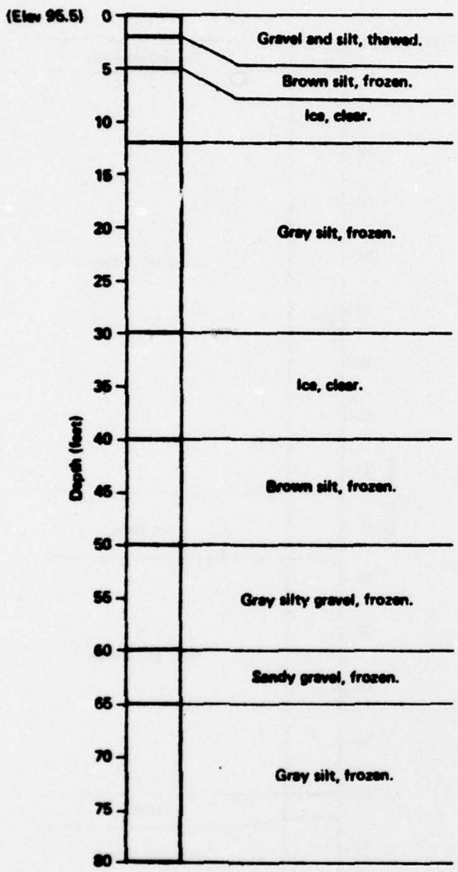


*Figure A9. Drill log for hole no. 9.*

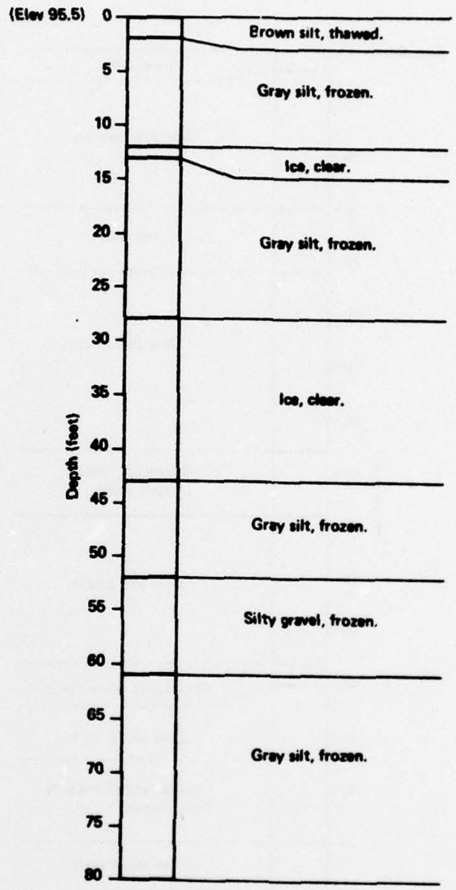


*Figure A10. Drill log for hole no. 10.*

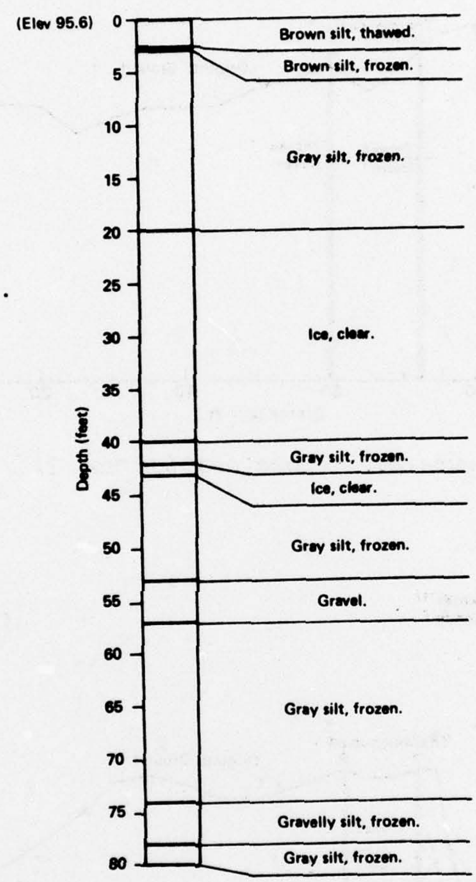


*Figure A11. Drill log for hole no. 11.*

APPENDIX B: CROSS SECTIONS AT VORTAC DAM

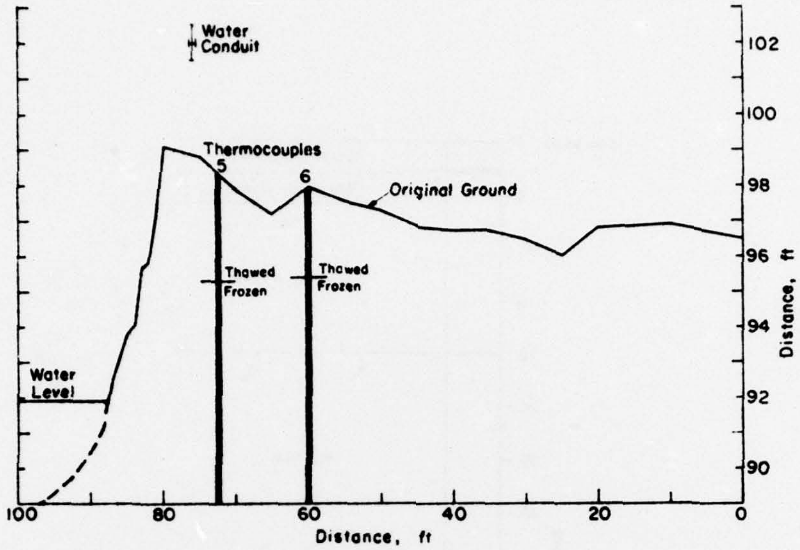


*Figure B1. Cross section no. 1.*

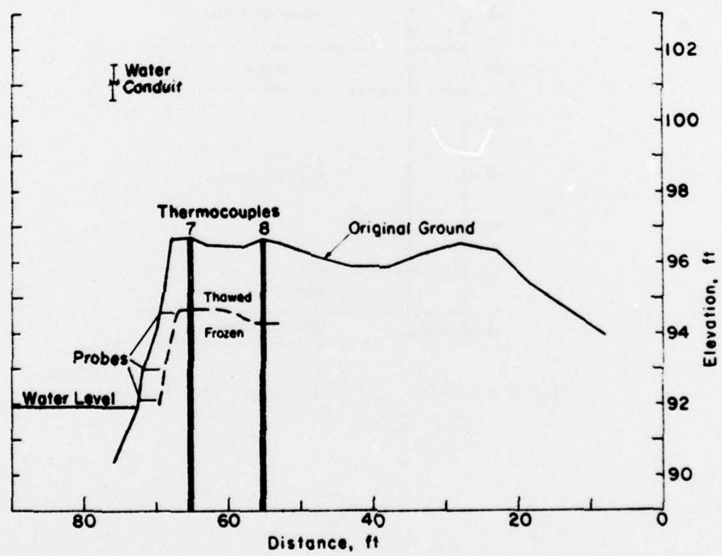


*Figure B2. Cross section no. 2.*

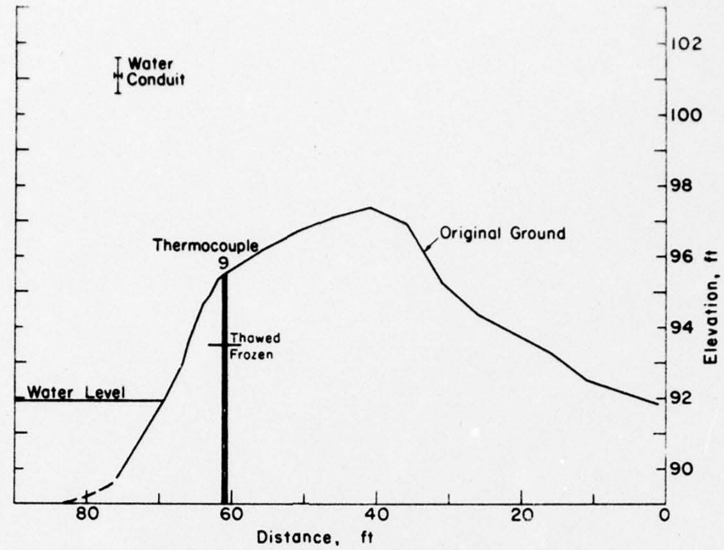


*Figure B3. Cross section no. 3.*

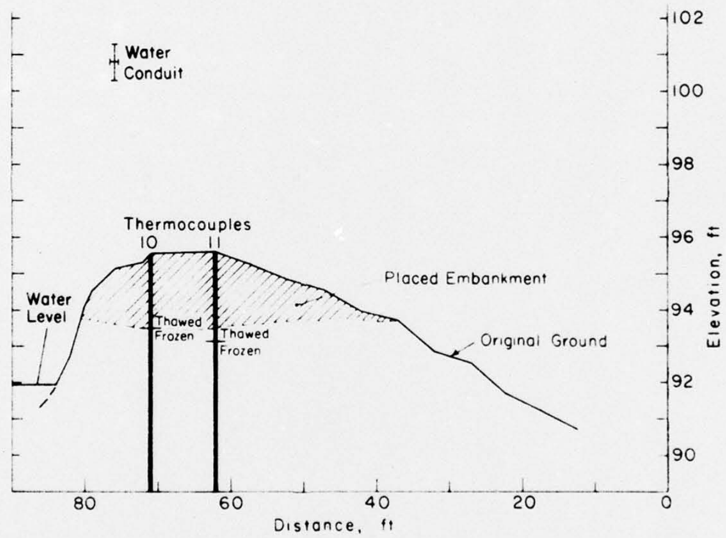


*Figure B4. Cross section no. 4.*

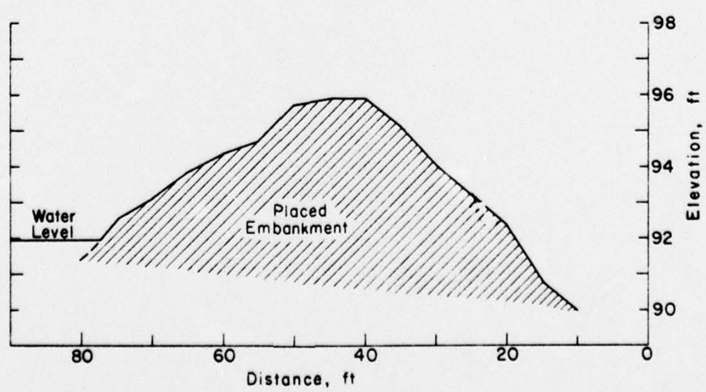


*Figure B5. Cross section no. 5.*